Control Architectures for Distributed Control of Mobile Robots

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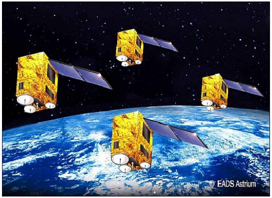
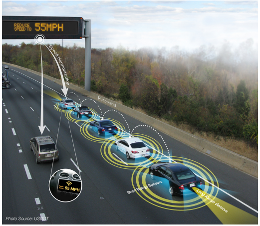
Motivating Scenarios

. Schooling in fish

Deep Water Horizon (2010)



. EADS Astrium



Vehicle Platoons

Physical Agent Dynamics

Figure 1: Crazyflie

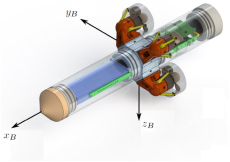


Figure 2: Hippocampus

Figure 3: Zooids

- Single/double integrator dynamics
- Linear Time Invariant (LTI)/Linear Parameter Varying (LPV) dynamics
- with/ without non-holonomic constraints

Core Idea

- Control of a single non-linear (possibly non-holonomic) agent: Well-studied problem and various techniques are known
  - LPV
  - Dynamic-inversion
  - Flatness-based control
- About 3 decades of work on studying interconnections of "simple" agent dynamics where simple could mean
  - single/ double integrator dynamics
  - positive systems

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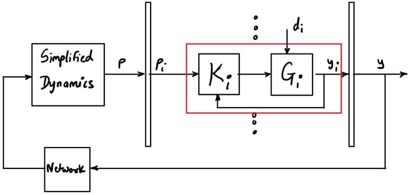
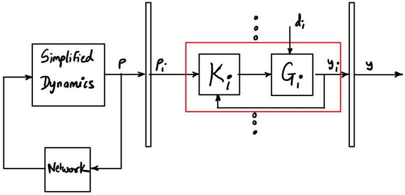
  - single/ double integrator dynamics
  - positive systems

Key questions:

- Can we maintain this separation in the controller design? i.e design local agent controllers and study the interconnections of these closed loop "simplified" systems
- Can we give some stability and performance guarantees with such a strategy?
- What kind of control architectures are possible?

Different Control Architectures





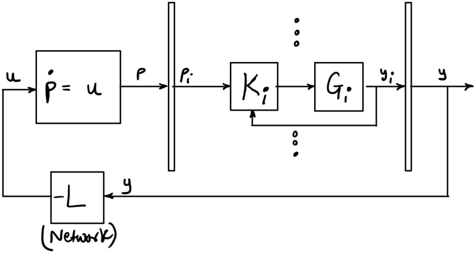
Coupled architecture

- Relative distances important
- Small inter-agent distances
- High disturbances

Decoupled architecture

- Absolute COM position important
- Large inter-agent distances
- Low disturbances

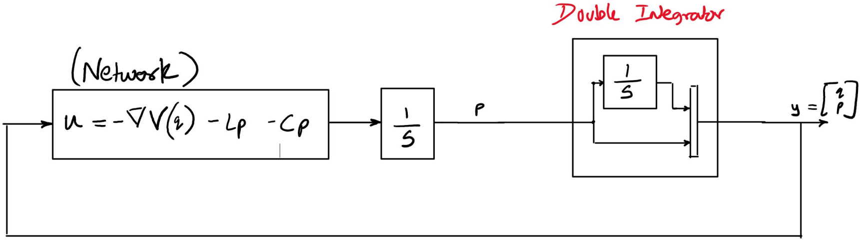
Coupled architecture: Consensus/ Formation control



- Some related work
  - Fixed Laplacian and LTI agents [1] -> Modal decomposition
  - Fixed and uncertain Laplacian and LPV agents [2] -> Modal decomposition
  - Flocking with a fixed Laplacian [3]
  - Interconnections of dissipative systems [4]

[1] Fax and Murray, 2004
[2] Popov, 2009, Eichler and Hoffmann,2014
[3] B.Francis, 2016
[4] M. Spong, 2006

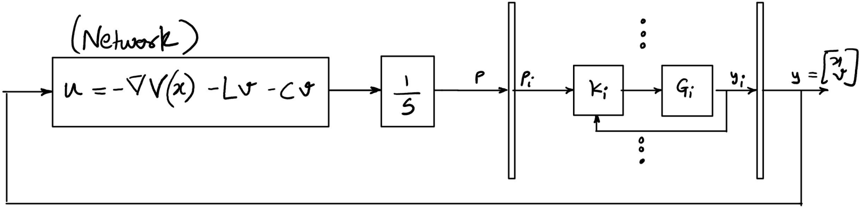
Coupled architecture: Flocking



- Flocking of double integraor agents [5]
- Stability analysis via LaSalle

[5] Olfati Saber,2006

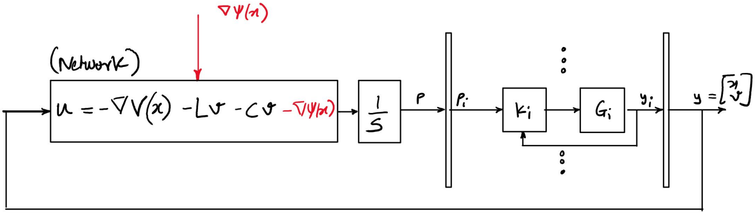
Coupled architecture: Flocking



- Flocking of quadrotors agents [6] but with fixed Laplacians
- Our experiments show that Quadrotors can be made to act like double integrators by well-tuned velocity controllers

[6] Francis, 2016

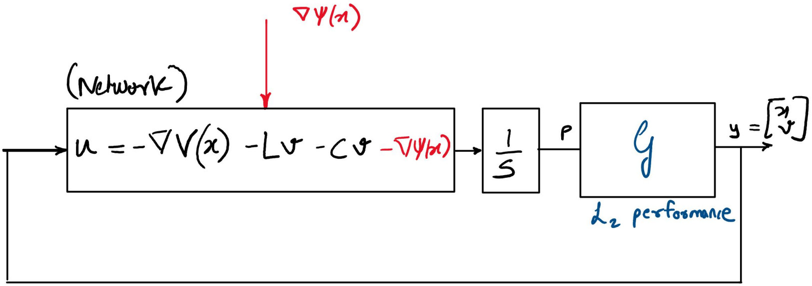
Coupled architecture: Flocking and source-seeking [7]



- Forcing dynamics due to a scalar field
- Convergence analysis(Asymptotic stability) for double integrator agents
- Experiments by designing good local velocity controllers

[7] Datar, Paulsen, Werner, 2020

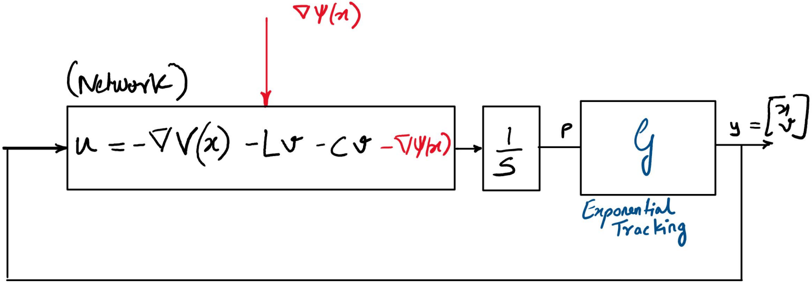
Coupled architecture: Flocking and source-seeking with non-linear agents [8]



- From double integrators -> non-linear (LPV) agents
- Stability isL(not asymptotic)

[8] Atallah, Datar, Werner, 2020

Coupled architecture: Some speculative ideas and open questions

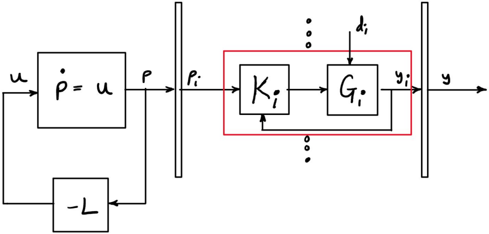


- Use IQCs to obtain exponential convergence rates[9] of local closed loops and use singular perturbation argument such as in [10]

[9] Boczr,Recht,Lessard,Packard,2017

[10] Mesbahi and others,2018

Decoupled architecture: Consensus/ Formation control



- Some related work
  - Idea of wrapping local controllers around first order dynamics [11]
  - Combine a cooperation module with consensus moduke [12]
  - Discrete-time Information flow filter [13]

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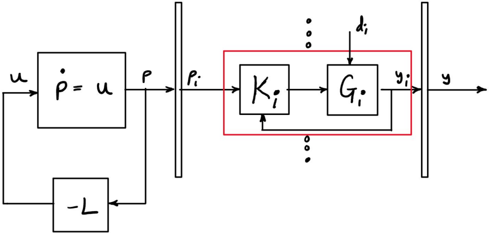
[11] Egerstedt and Cortes,2017
[12] Chen and Ren, 2019
[13] Fax and Murray, 2004

Decoupled architecture: Formation forming



- Gen H2 norm[14]
- Positive systems theory in the network loop[15]
- Crazyflie experiments [16]

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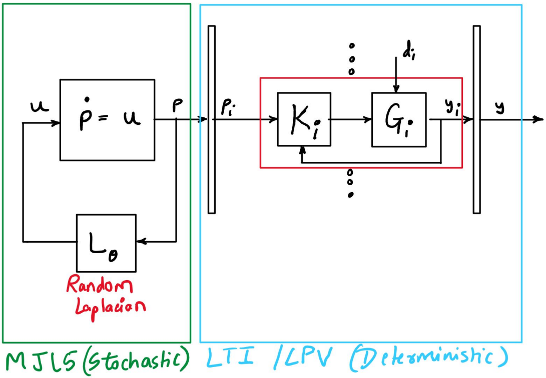
[14] Hespe, 2020
[15] Datar, 2020 (Submitted)
[16] M. Thesis, Paulsen,2019

Decoupled architecture: Non-ideal networks



- Model the Information flow dynamics as a Markovian Jump Linear System(MJLS)
- r2 or w2 measures (Daniel will talk more about this)
- IQC analysis of consensus Dynamics [17] -> Scalable condition

[17] Rantzer, 2016

Thank you